



VERITAS Observations of Galactic TeV Sources

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GeV and TeV Sources in the Milky Way
Aspen Summer Workshop **June 2010**

Galactic Sources with VERITAS



- General Observation Strategy:
 - Limited Blind Survey
 - Pointed Observations
 - Both of these have led to detections.
- This talk:
 - VERITAS Overview
 - Survey
 - Galactic Binaries

Brian Humensky:
SNR and PWN

VERITAS: Fall 2007



- **Smithsonian Astrophysical Observatory**
- **Purdue University**
- **Iowa State University**
- **Washington University in St. Louis**
- **University of Chicago**
- **University of Utah**
- **University of California, Los Angeles**
- **McGill University, Montreal**
- **University College Dublin**
- **University of Leeds**
- **Adler Planetarium**
- **Argonne National Laboratory**
- **Barnard College**

- **DePauw University**
- **Bartol Research Institute/ University of Delaware**
- **Grinnell College**
- **University of California, Santa Cruz**
- **University of Iowa**
- **University of Massachusetts**
- **Cork Institute of Technology**
- **Galway Mayo Institute of Technology**
- **National University of Ireland Galway**
- **~25 Associate Members**

<http://www.youtube.com/watch?v=ucP1dAXfYtQ>

VERITAS

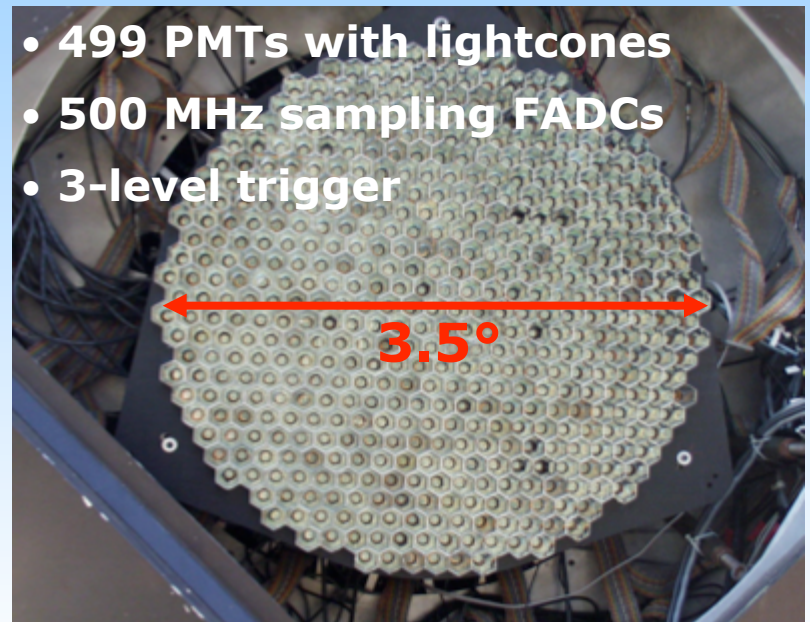
- Situated at 1250m altitude at the Whipple Observatory near Tucson



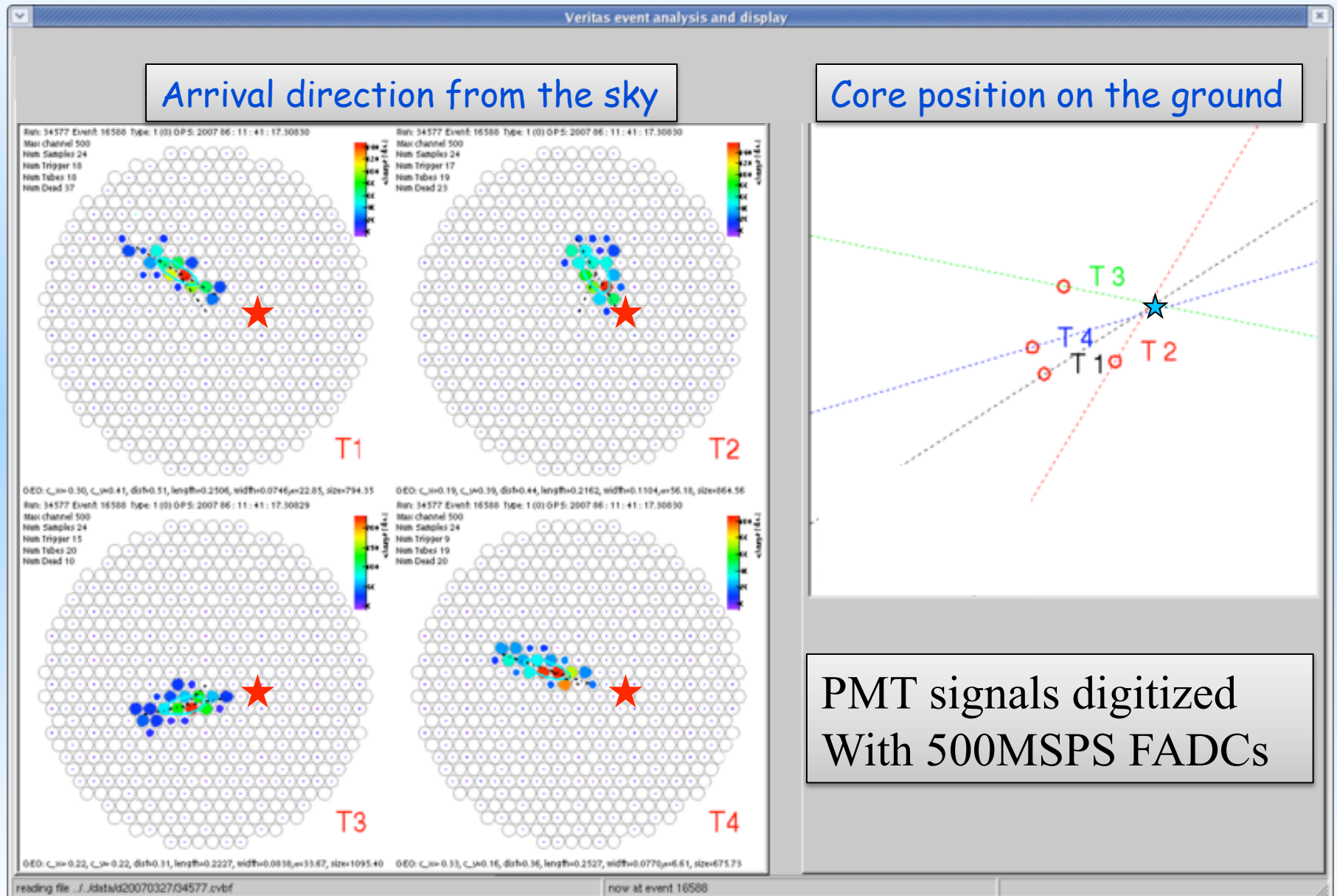
- 111m^2 tessellated mirror
- Recoated every ~ 2 years



- 499 PMTs with lightcones
- 500 MHz sampling FADCs
- 3-level trigger



Data



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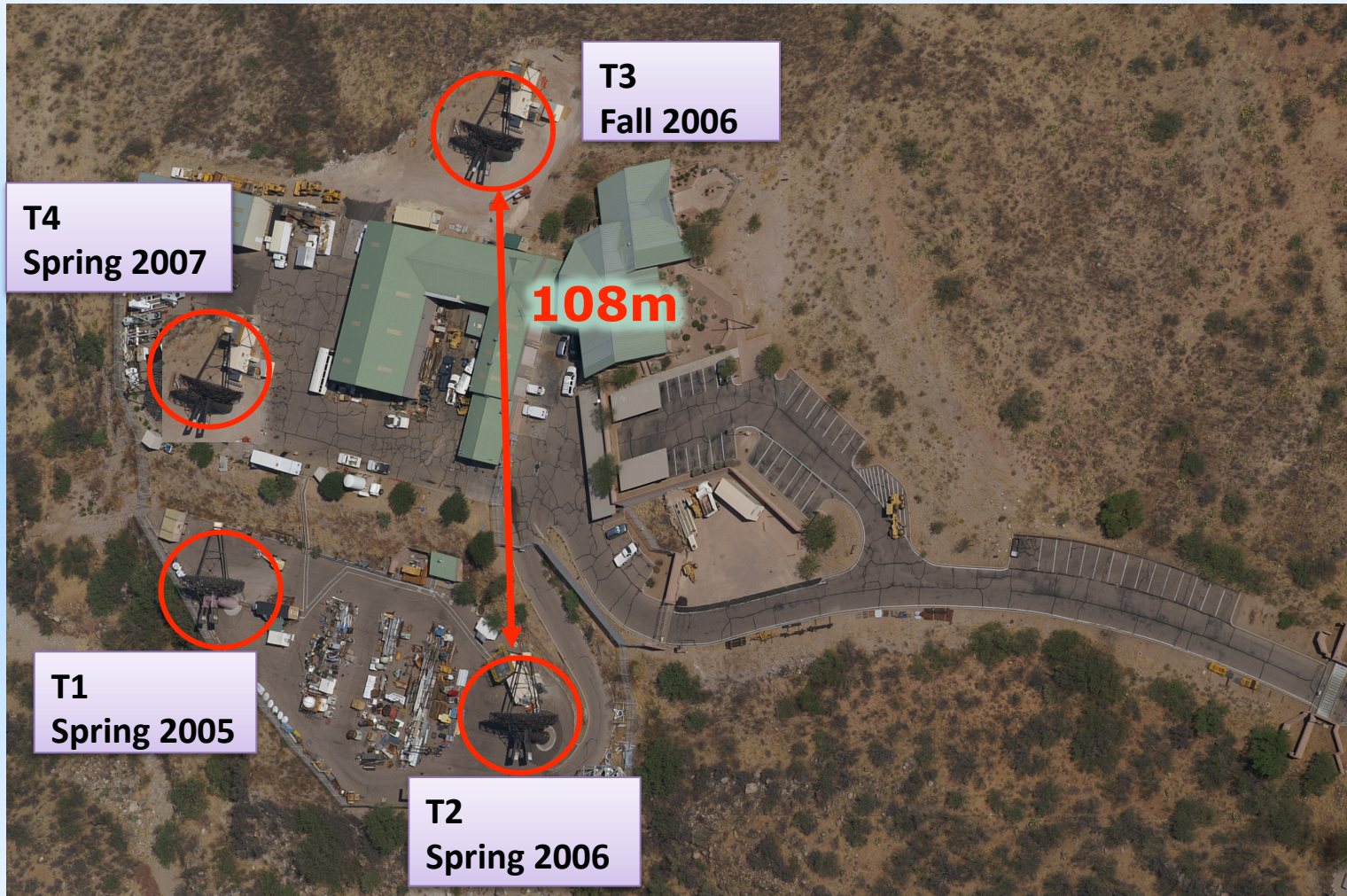
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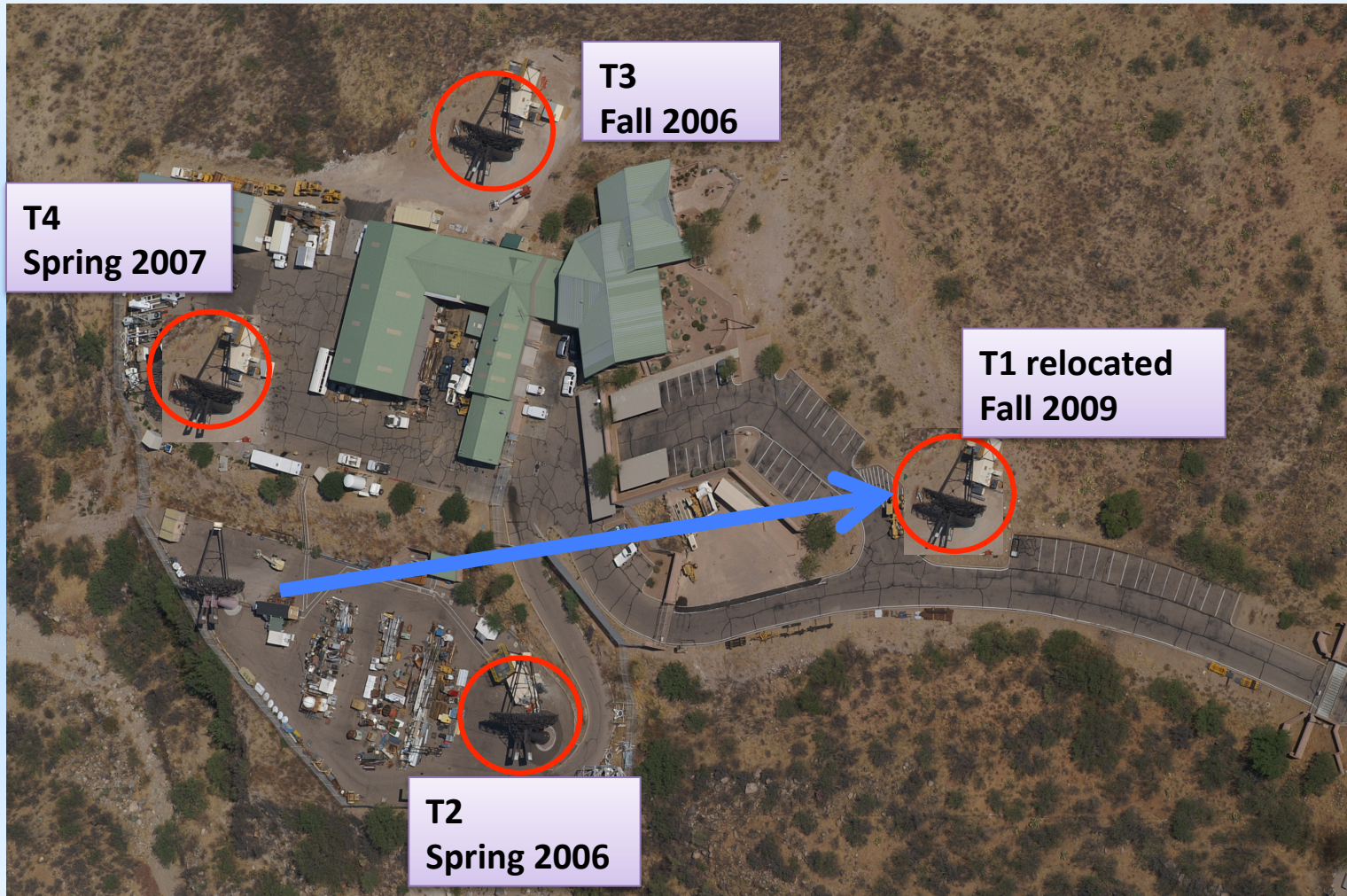
VERITAS: Fall 2009



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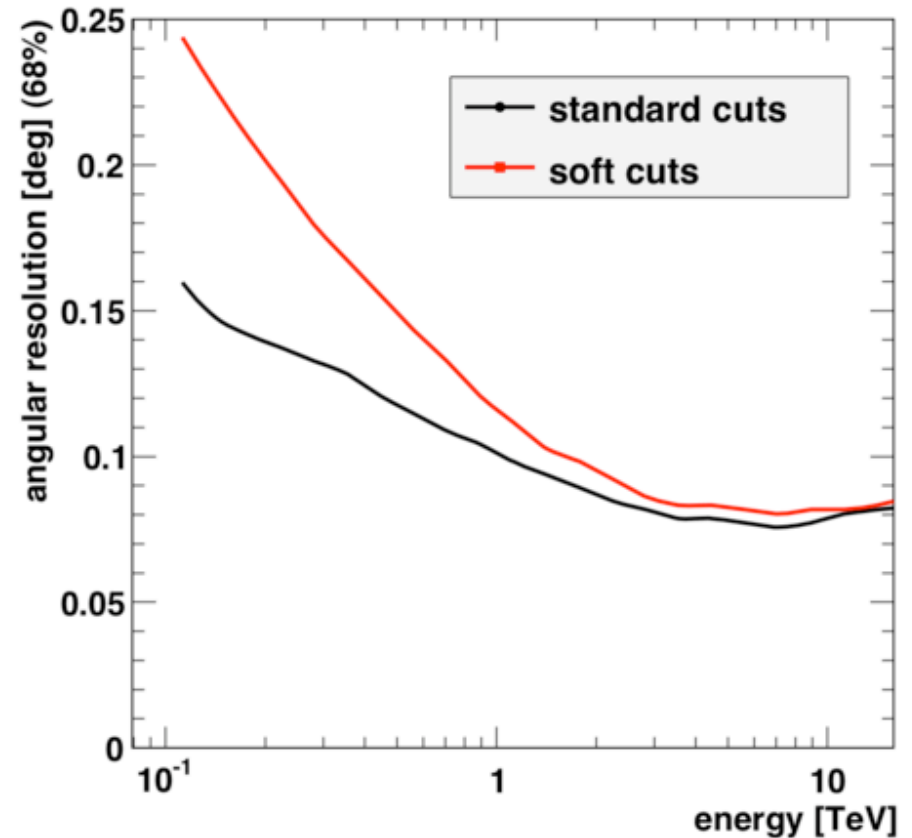
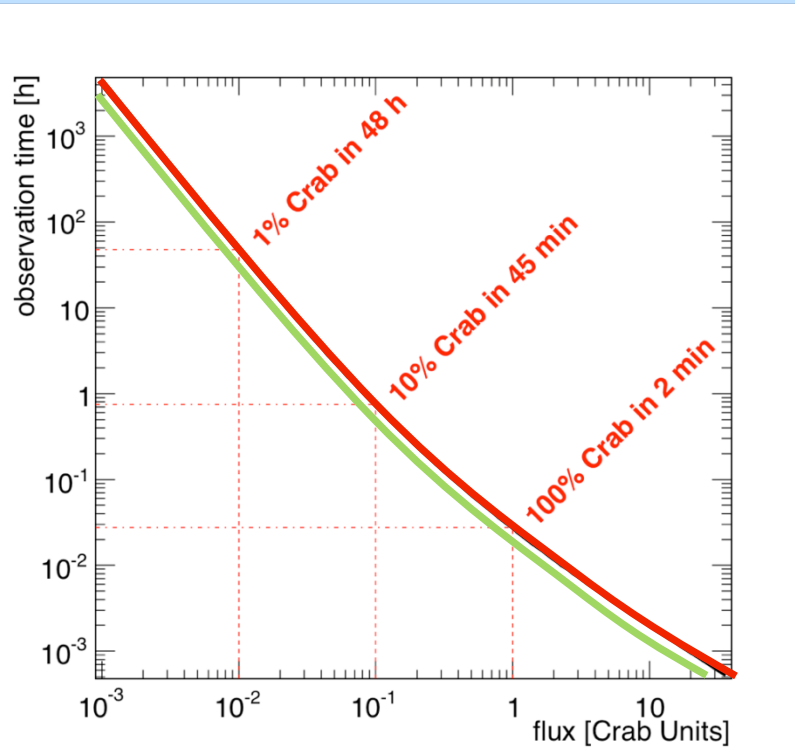
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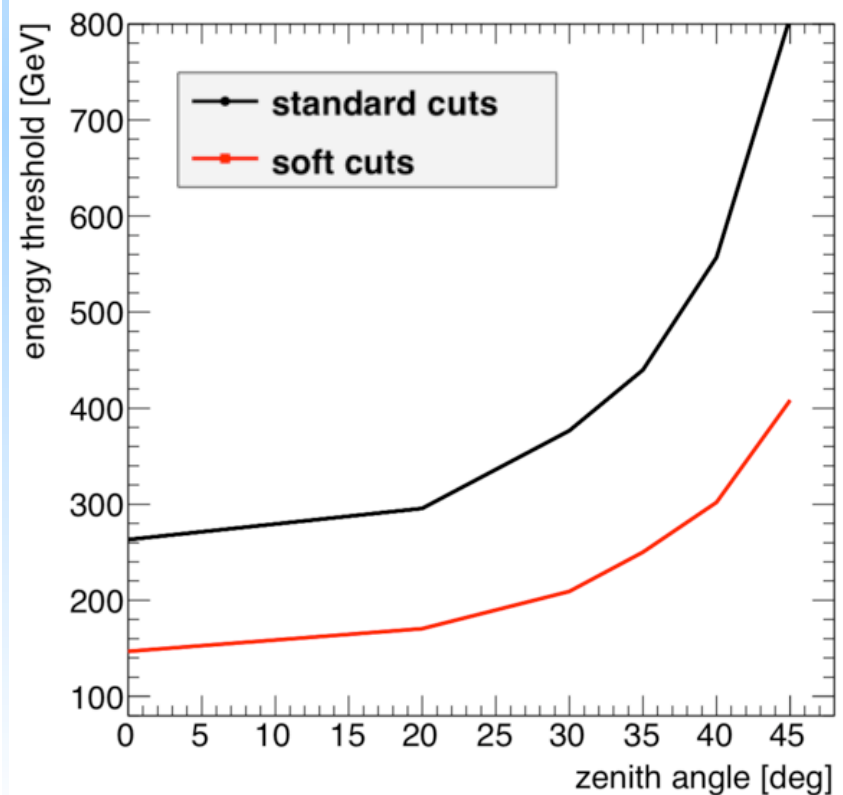
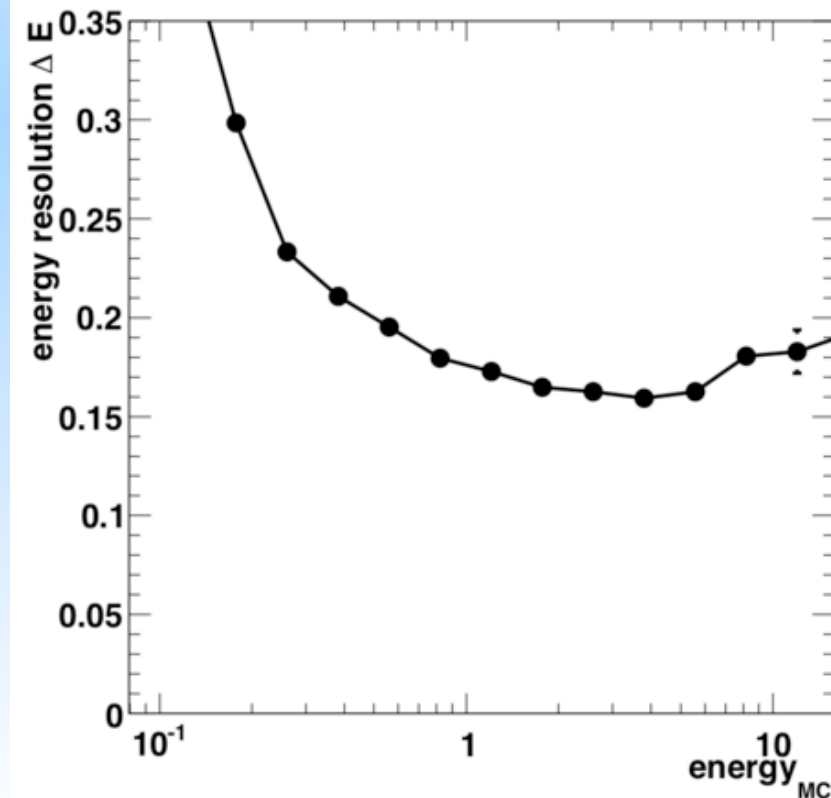
VERITAS Technical Performance

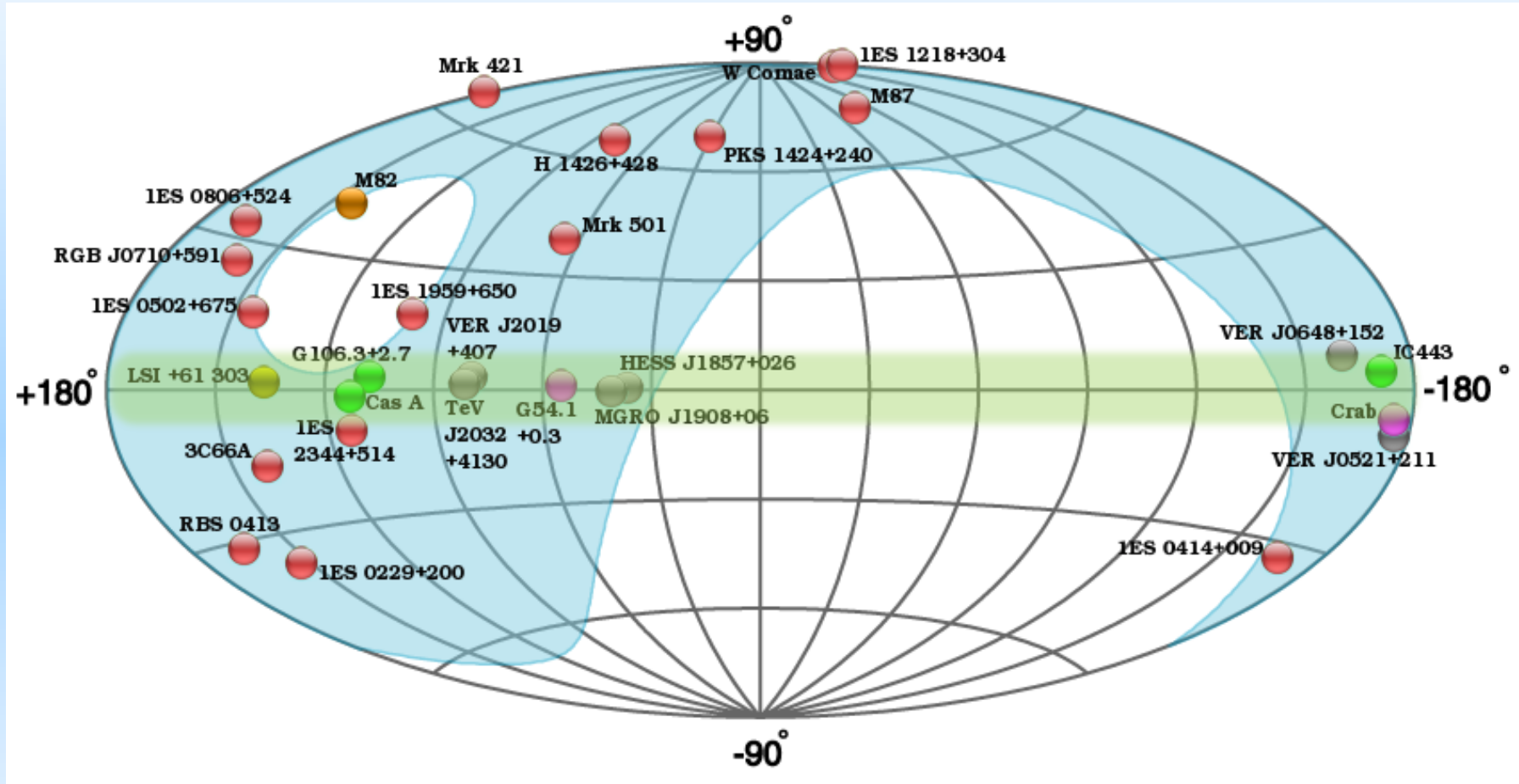
- Sensitivity improved from 1% Crab in 50 hours to 1% Crab in 30 hours
- Currently the most sensitive in the world;
- Recently received MRI-R² funding for a further upgrade.
- Angular resolution $\sim 0.1^\circ$ (68% containment)



VERITAS Technical Performance

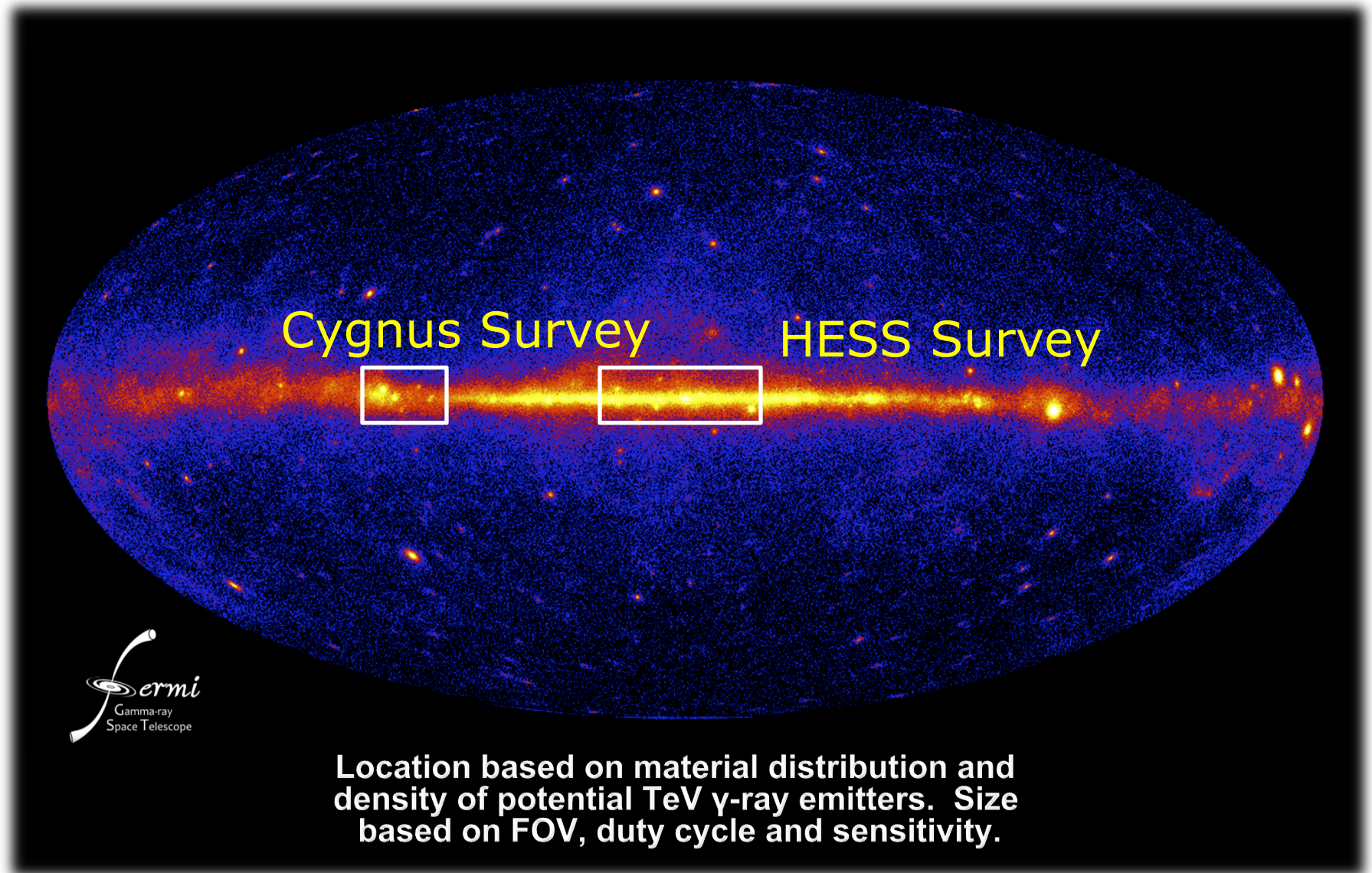
- Energy resolution $\sim 15\text{-}20\%$ $> 300\text{ GeV}$
- Energy threshold $\sim 150\text{ GeV}$



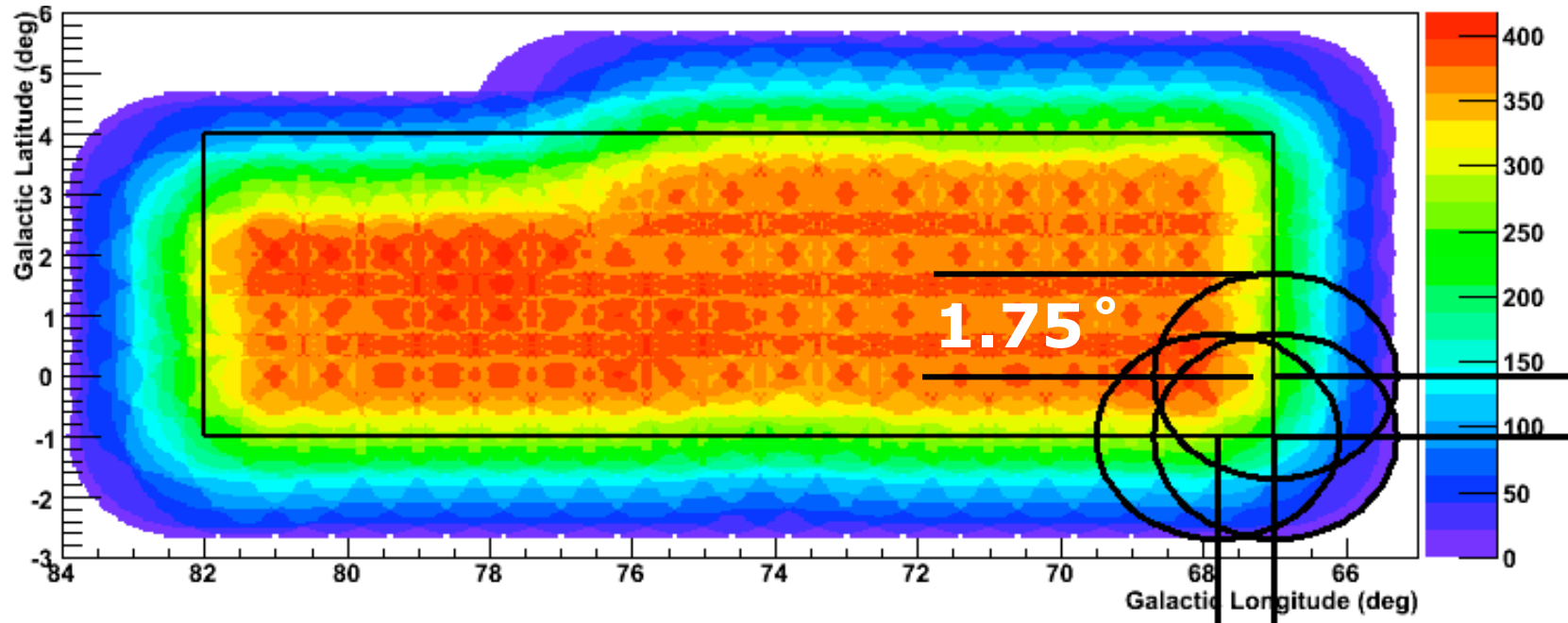


**30 Sources in 6 Source Classes
(including Tycho's SNR!)**

VERITAS Sky Survey



VERITAS Sky Survey II

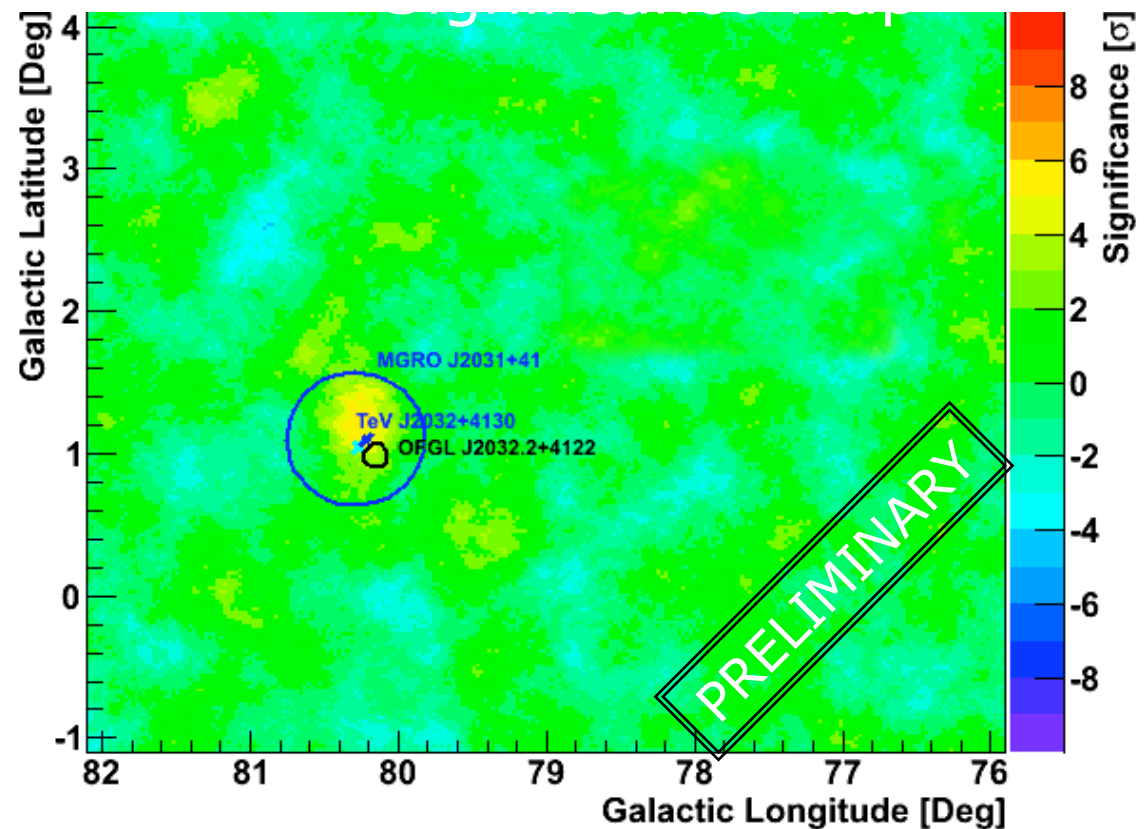


- 2007-2009, 112 base hrs with 56 hrs of follow-up studies
- Cygnus Region Coverage: $67^\circ < l < 82^\circ$, $-1^\circ < b < 4^\circ$
- 4 pre-defined cut-sets (hard/soft, point-like/extended)
- Depth: $< 3\%$ Crab above 200 GeV [99% CL] for point-like sources

One Particularly Interesting Region

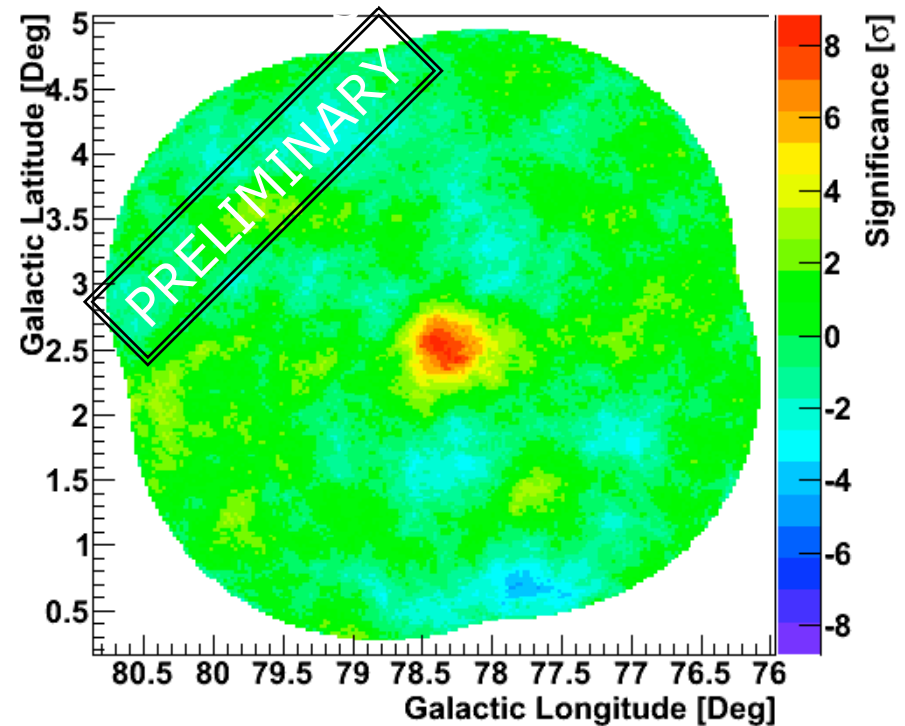


- Subset of Survey
 - Hard/Extended cuts
- TeV J2032+4130
 - Known source, first detected by HEGRA
 - Possible Associations:
 - CYG OB2
 - MGRO J2031+41
 - 1FGL J2032.2+4127/0FGL J2032.2+4122
 - VERITAS Detection is $>5\sigma$ at nominal position (no trials)
- New Source!
 - VER J2019+407





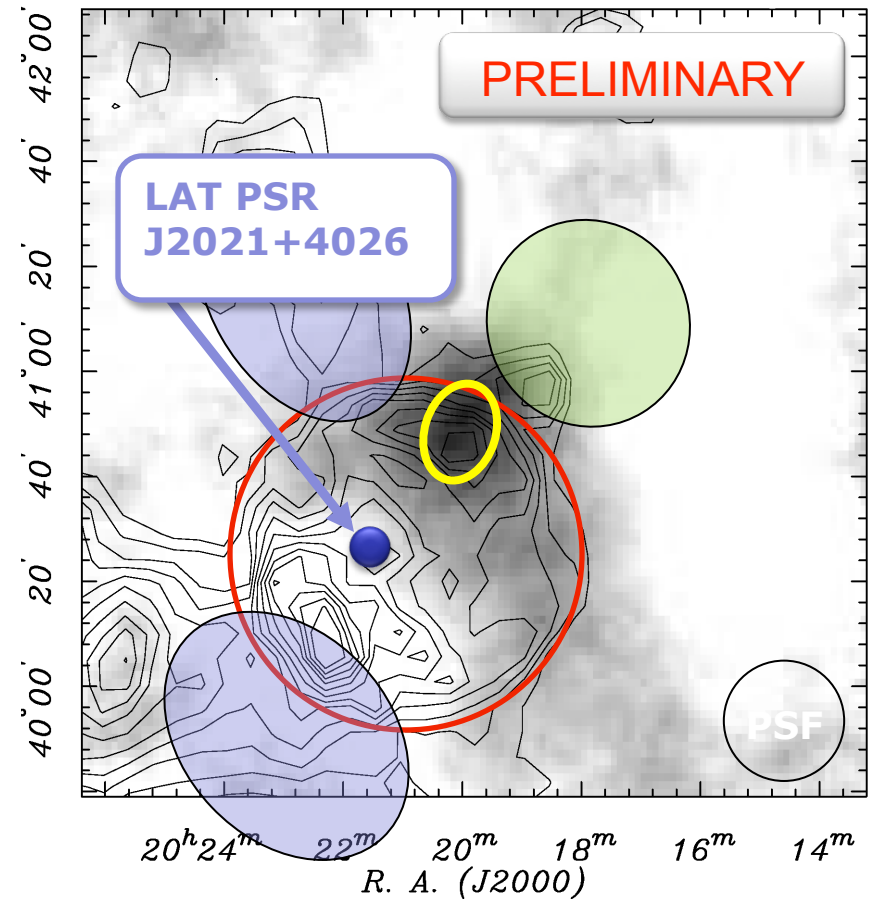
- Early Follow-up candidate
 - Independent data set from Fall 2009 confirms existence of a new source at $\sim 7.5\sigma$.
 - Preliminary Flux level above 1 TeV: $\sim 3\%$ Crab
 - Preliminary Extension:
 - $\sim 0.2^\circ$ Symmetric Gaussian Fit



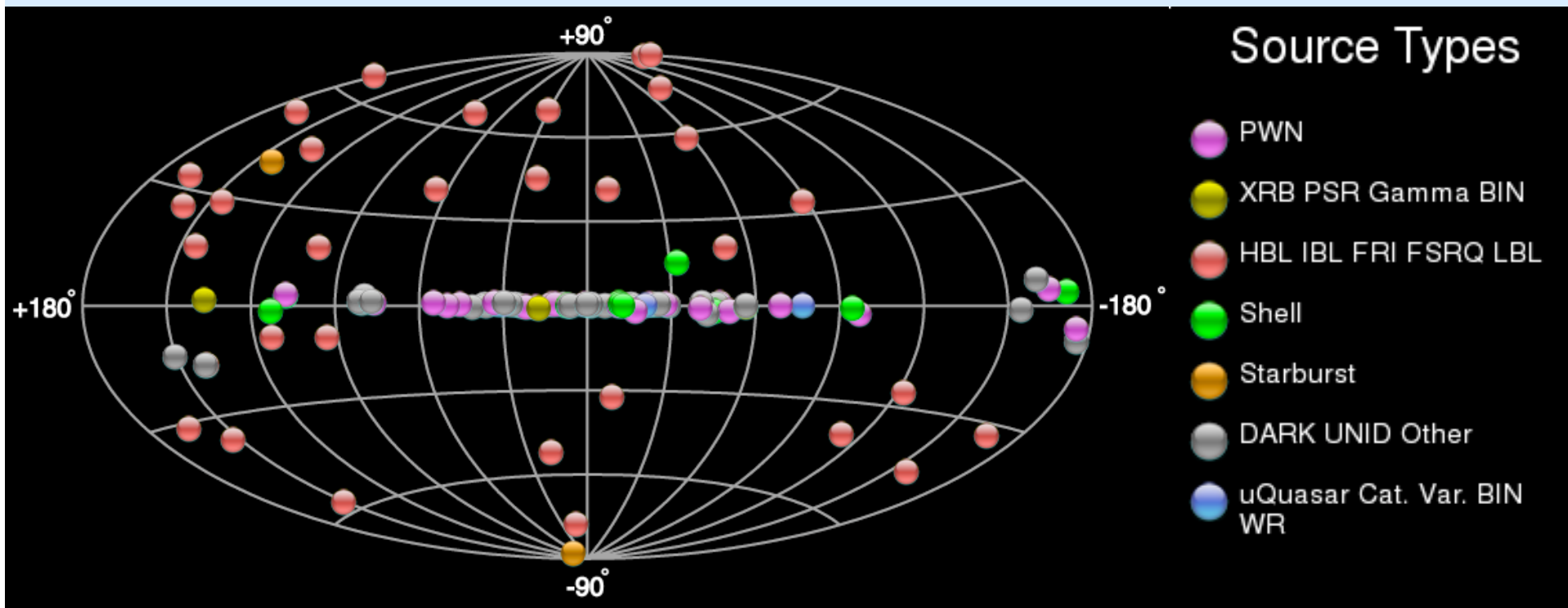
VER J2019+407 II



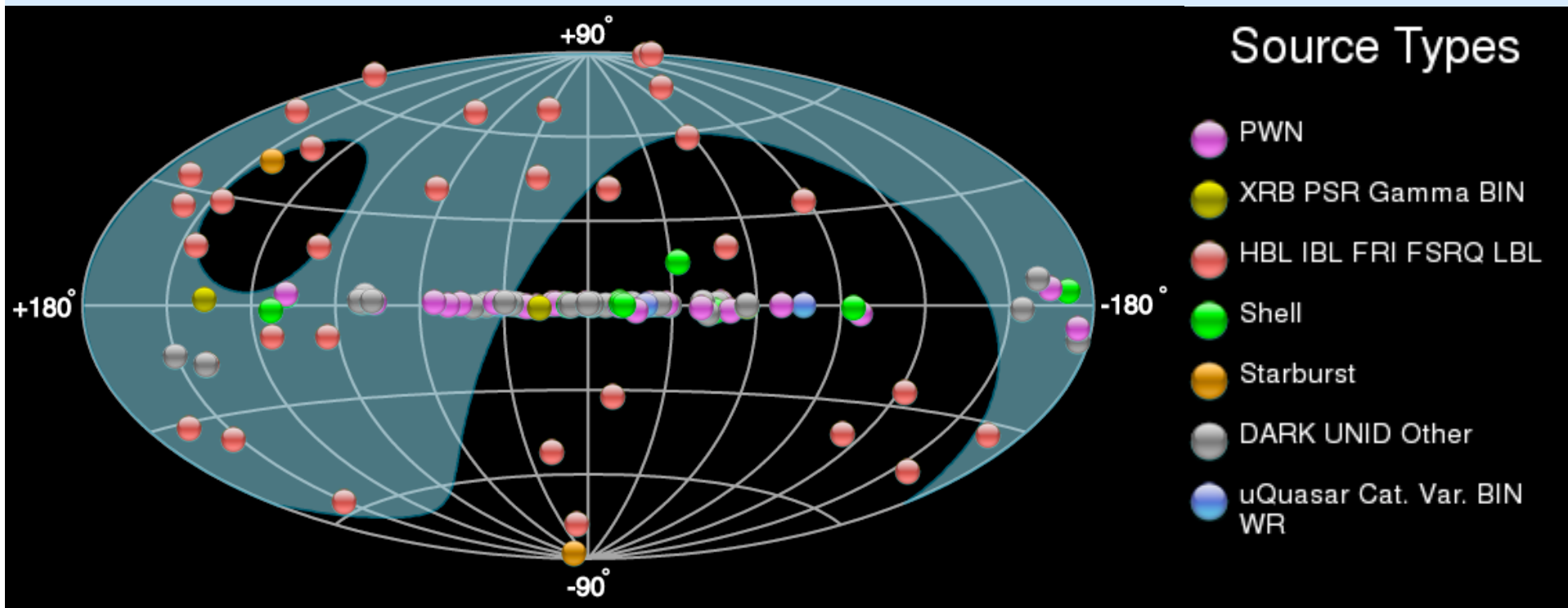
- Peak in NW corner of G78.2+2.1 (γ -Cygni)
 - Distance $\sim 1.5 - 1.8$ kpc
 - Age $\sim 5-10$ kyr
- TeV Mechanism?
 - Is it the PWN of Fermi PSR J2021+4026?
 - Is it shock-matter interactions?
 - CO? Lots to the SE, not as much in the NW.
 - Partial HI shell to NW?
 - Shock overtaking cavity wall?



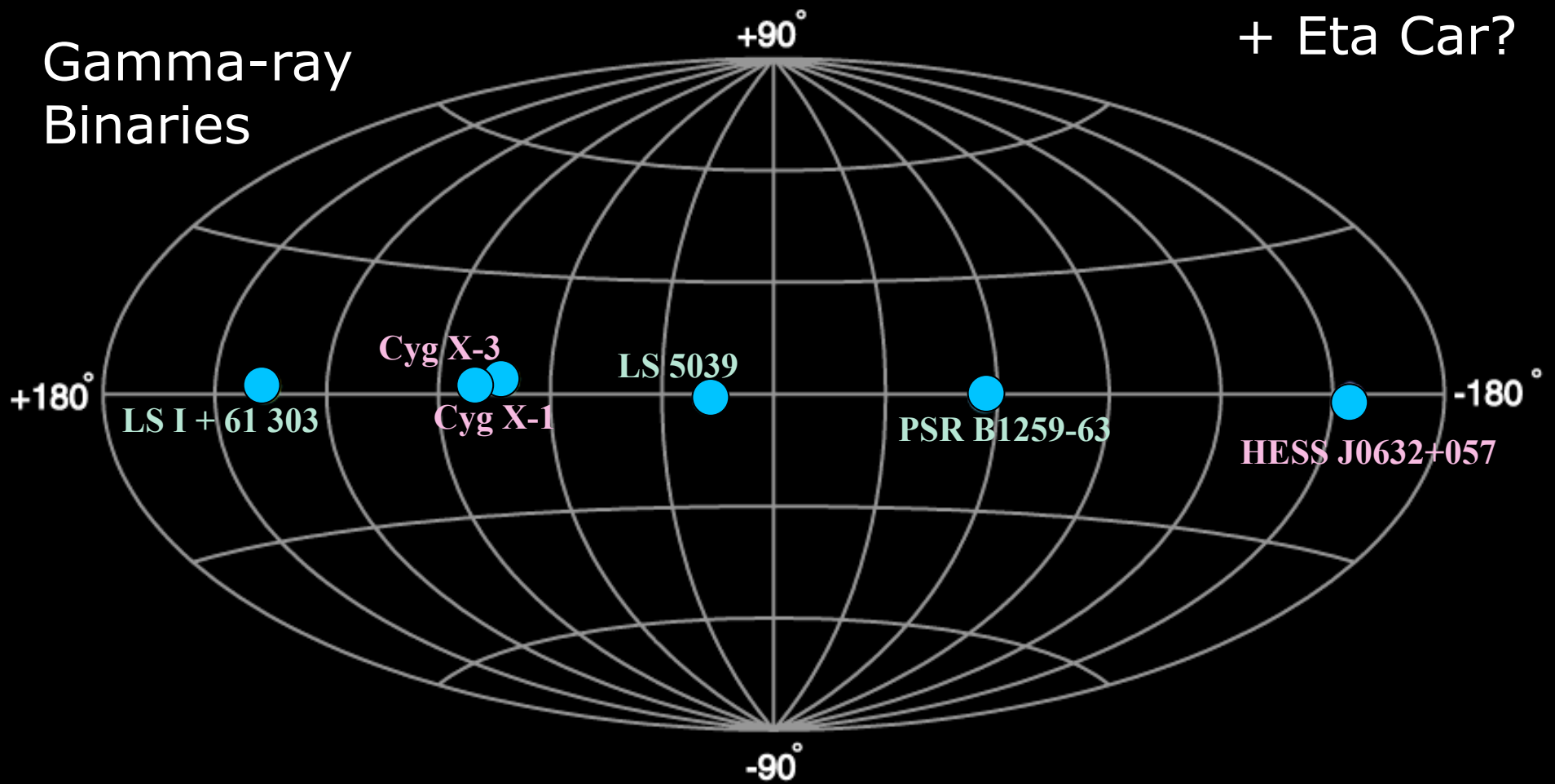
The TeV Sky, circa June 2010



The TeV Sky, circa June 2010



Gamma-ray Binaries

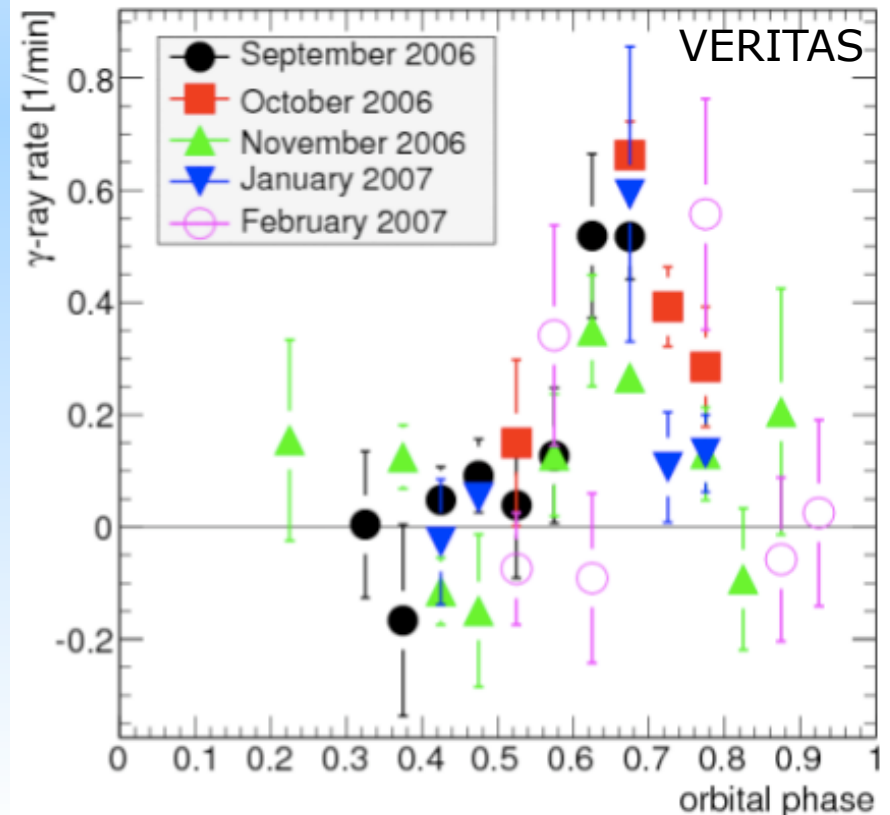
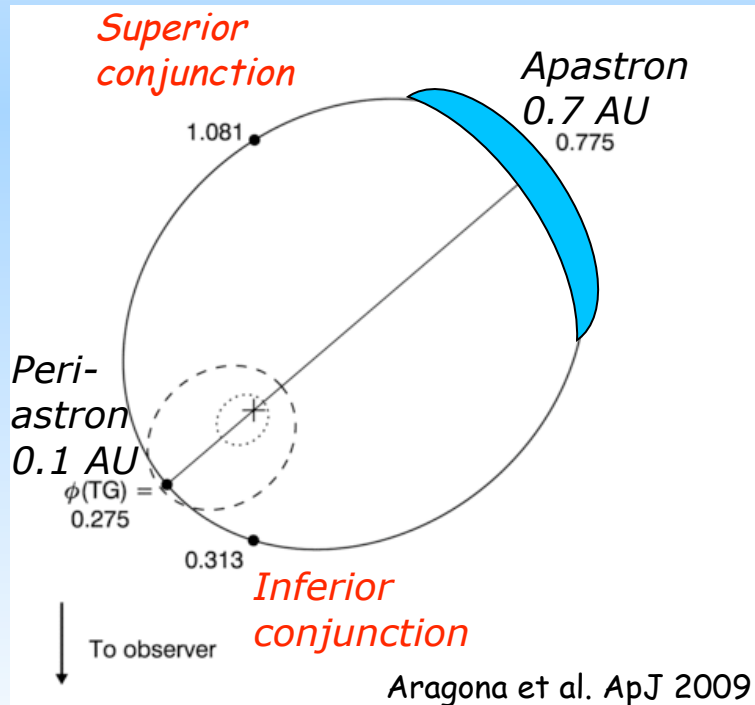


Why are these few so interesting?

- Binaries are the *only* variable galactic TeV sources
- They are natural particle accelerators operating under varying, but *regularly repeating*, environmental conditions
- Provide a constraining laboratory for models of particle acceleration, and gamma-ray production, emission and absorption processes
- May provide the keys to an understanding of astrophysical jets
- Each system is unique - and the population, as well as the data quality, is increasing

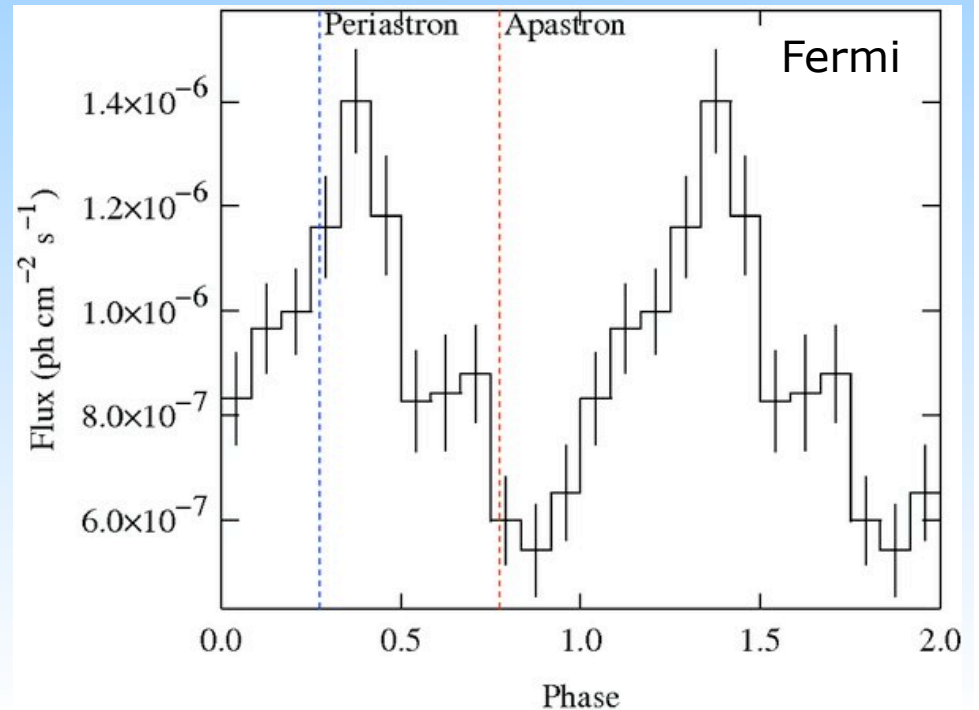
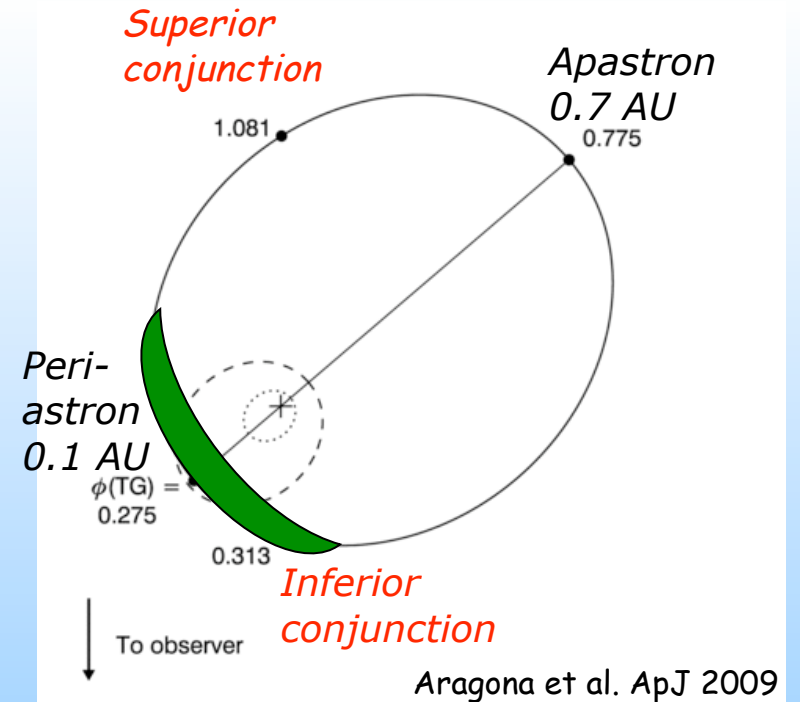
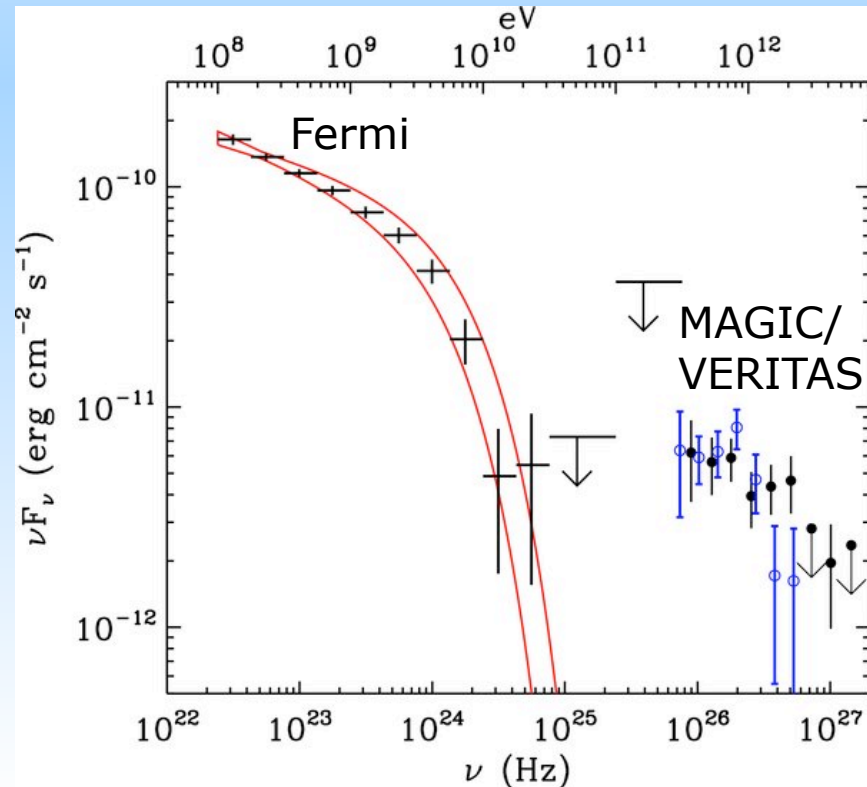
LS I +61° 303

- Compact object (Black hole or Neutron star) orbiting an B0Ve companion ($12M_{\odot}$)
- 26.5 day, inclined orbit, $e=0.54$, circumstellar disk
- extended radio structures; microquasar? but radio imaging shows morphology modulated by orbital position; pulsar wind.
- Whipple limits, detected by MAGIC, then VERITAS (8.4σ , $\Gamma=2.4\pm0.16_{\text{stat}}\pm0.2_{\text{sys}}$)
- Strong emission only detected near apastron ($\phi=0.5-0.8$)

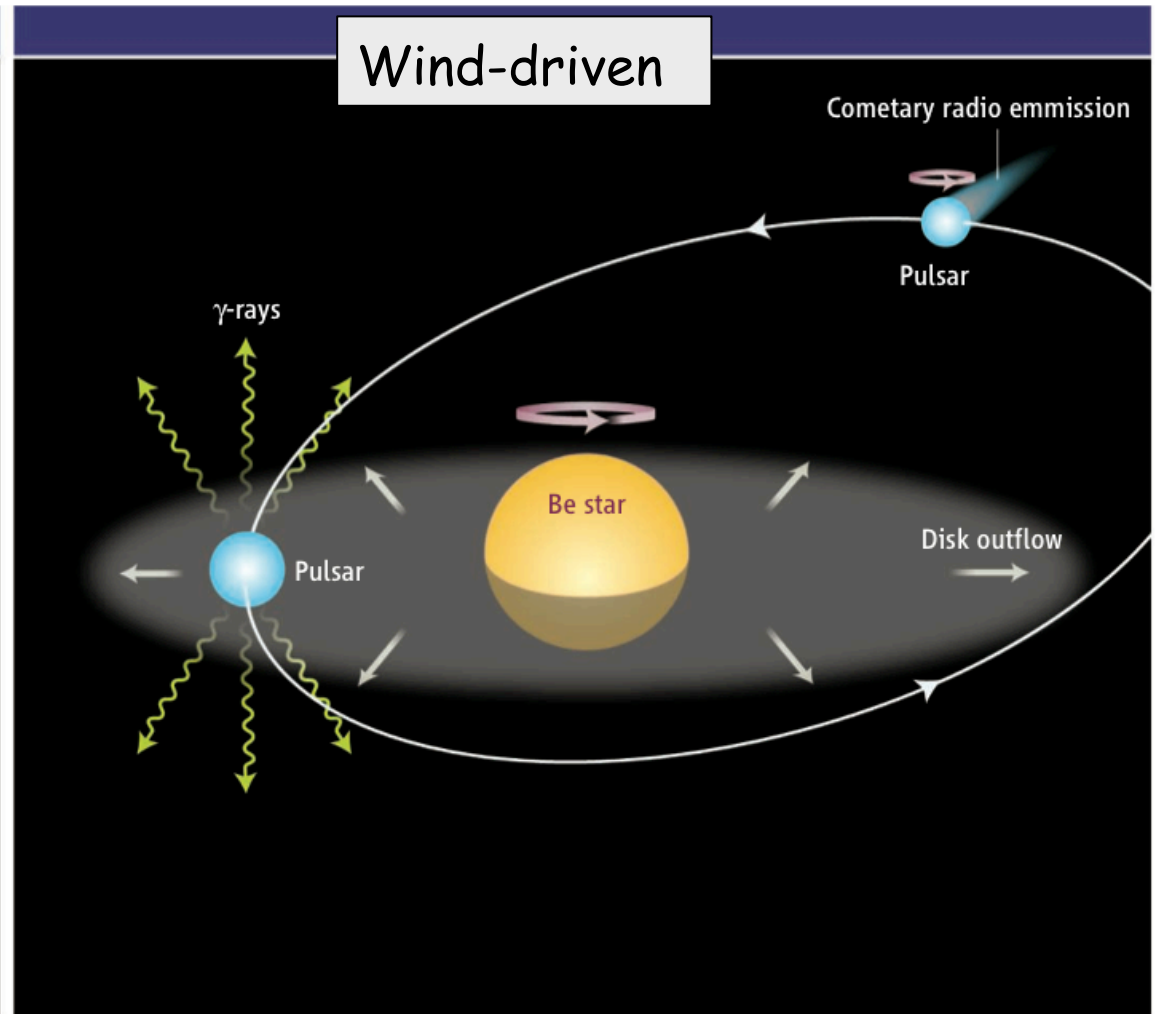
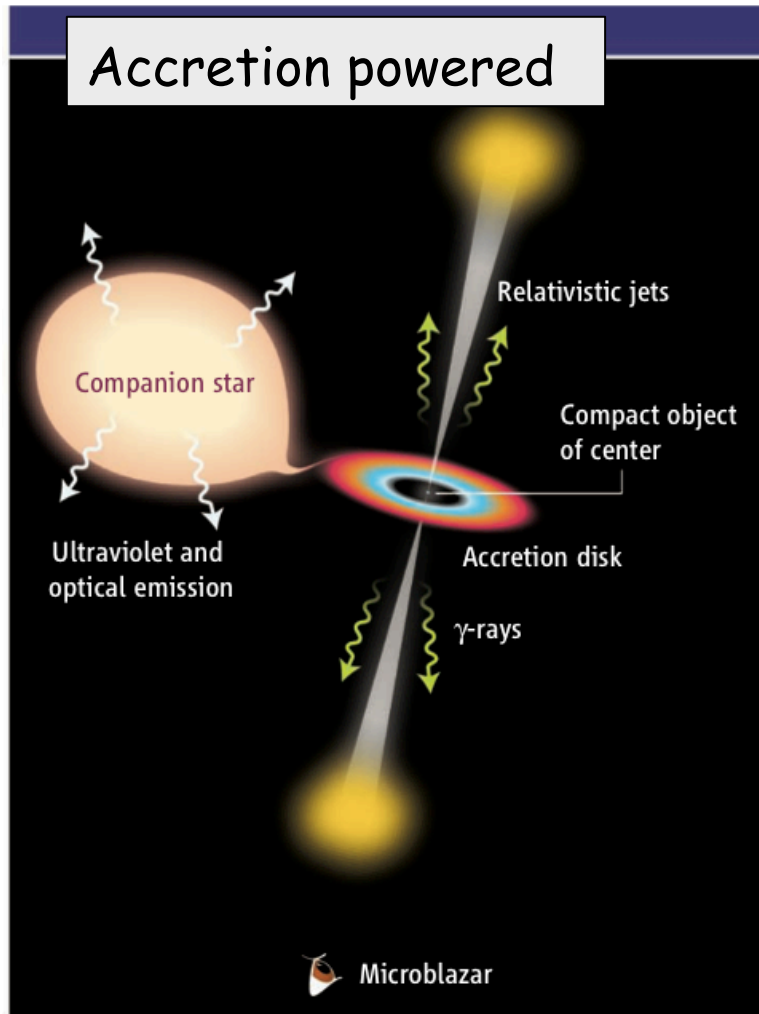


LS I +61° 303

- Detected by Fermi-LAT (BSL)
- Orbital modulation well measured
- Emission peaks near *periastron*
- **Cut-off** at 6 GeV observed between LAT and TeV - but not contemporaneous data



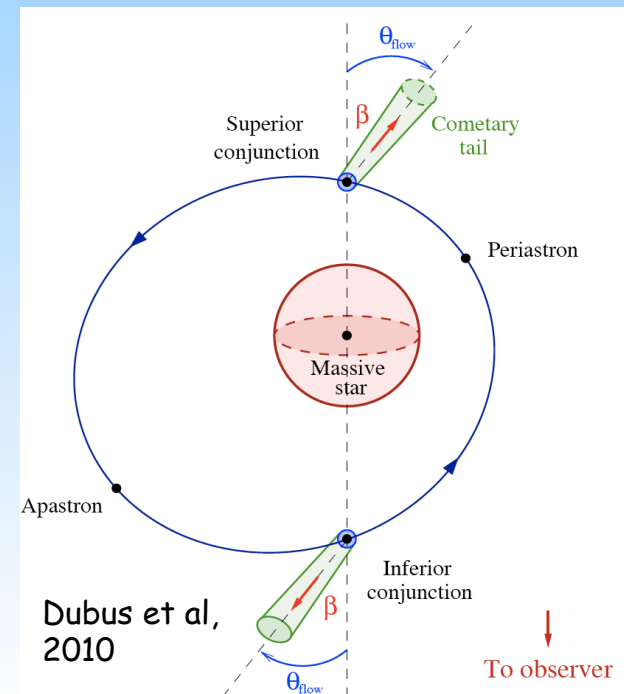
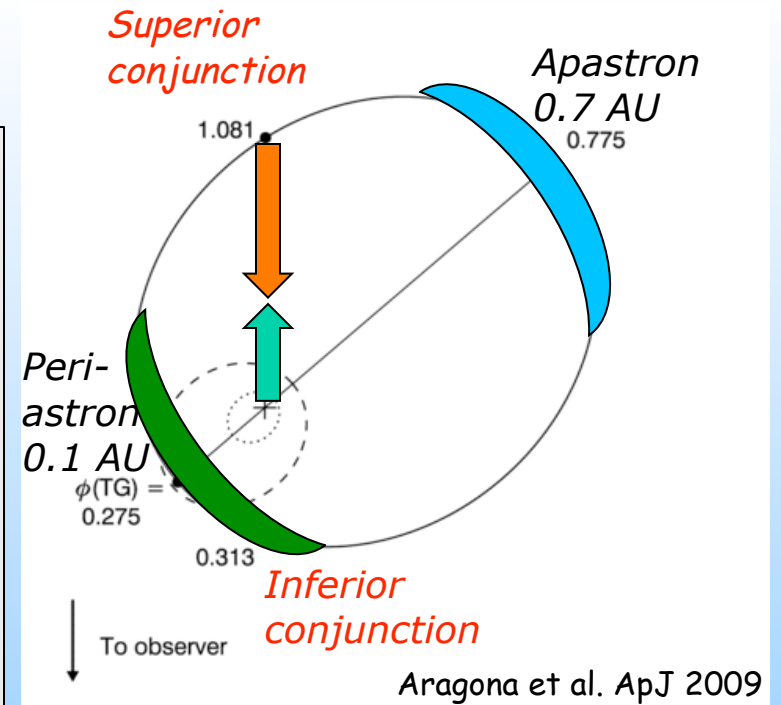
What's going on?



Mirabel (Science 309, 714, 2006)

LS I +61° 303

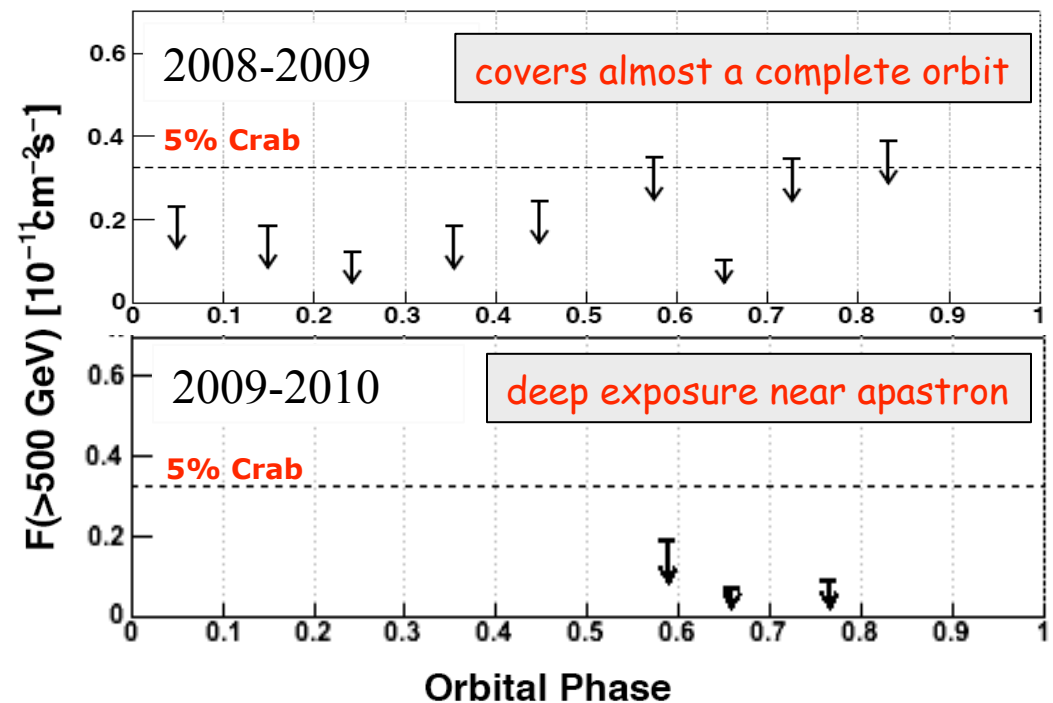
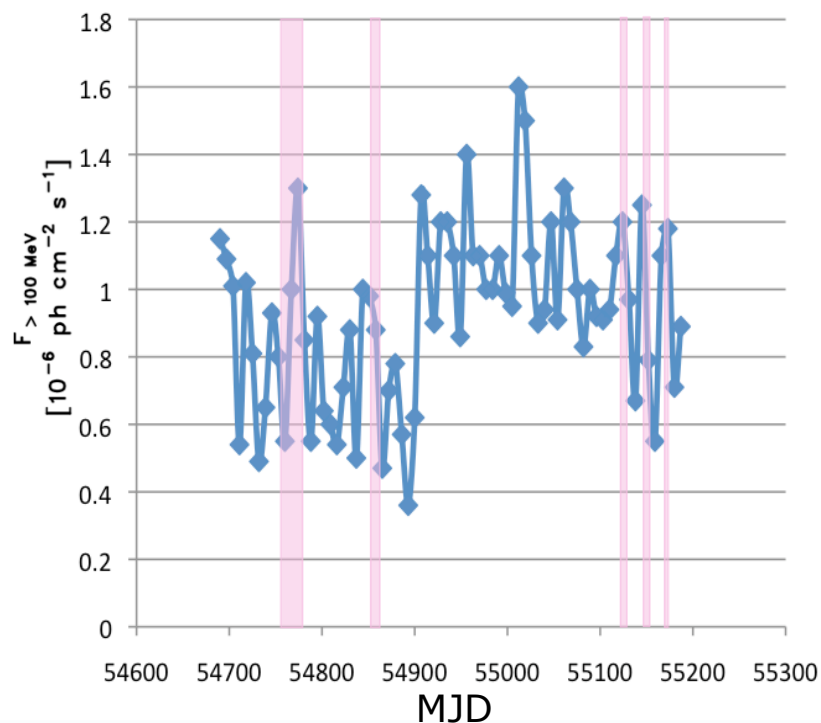
- Competing processes
 - Assuming Inverse Compton production \rightarrow high energy electrons boost stellar photons to gamma-ray energies
 - At superior conjunction, Inverse Compton production peaks over all energies
 - At superior conjunction, photons > 30 GeV are most heavily absorbed
- Doesn't fit the lightcurves very well
 - Moderate Doppler boosting helps
- Why is there a 6 GeV cut-off?
 - Different mechanism for GeV and TeV?
 - GeV emission spectrum looks like a pulsar - but then why is the GeV emission modulated at all? Where are the pulses?



LS I +61° 303

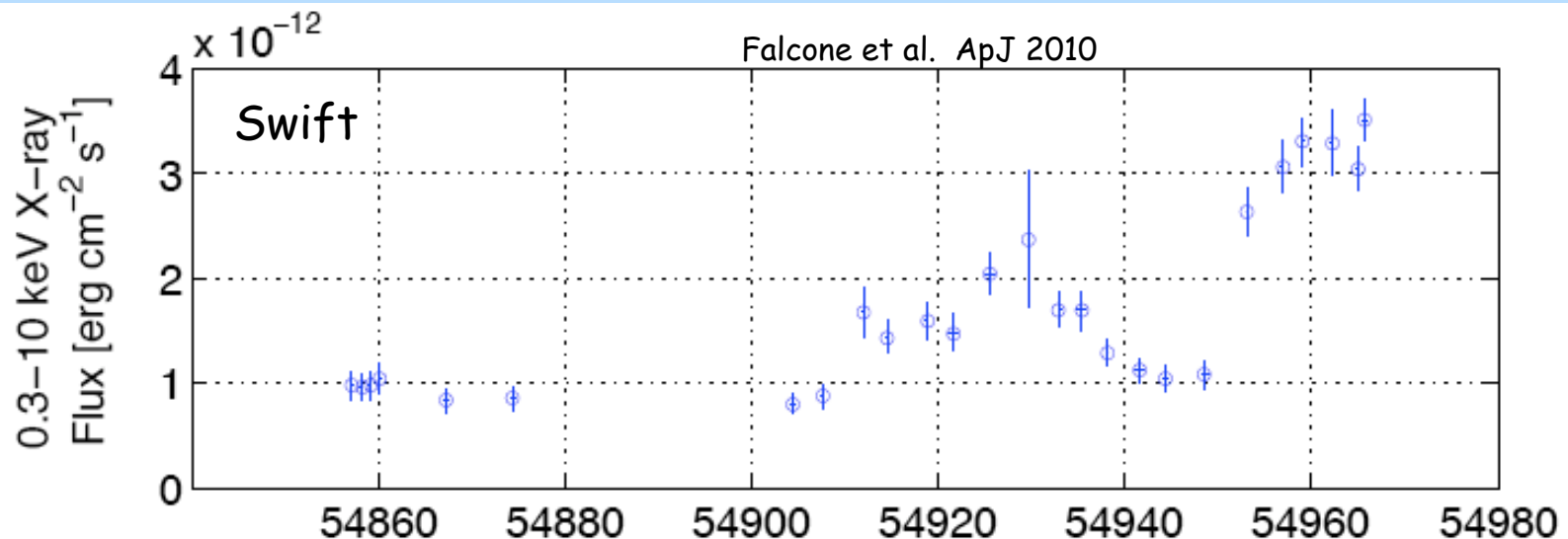
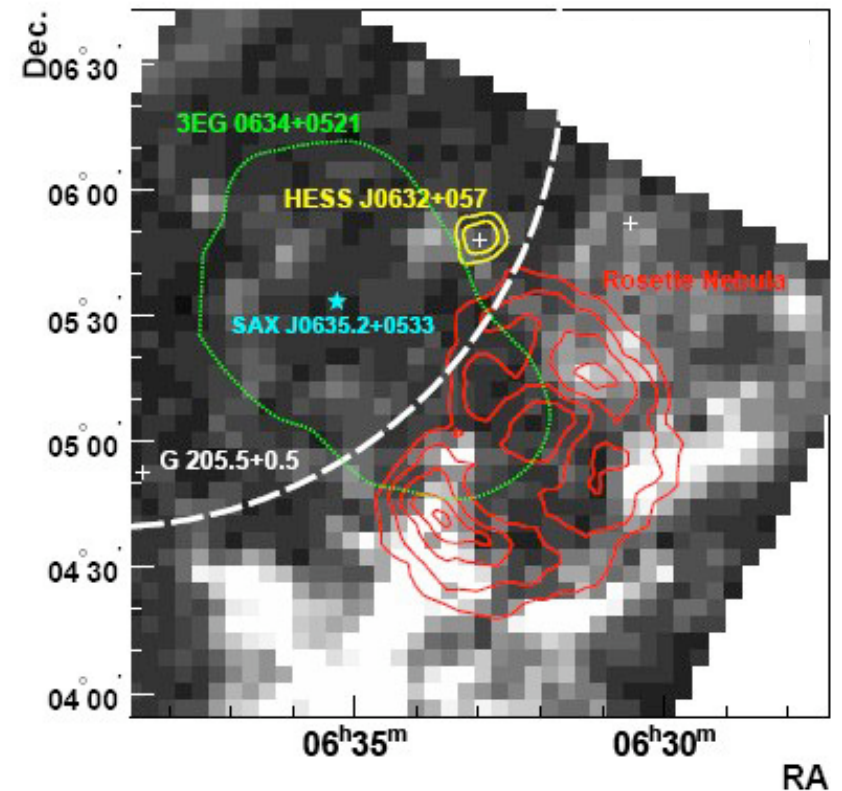
- Contemporaneous observations complicate things further
- No detection by VERITAS since the launch of Fermi, despite good exposure around apastron - but poor sampling...
- New FERMI result (Richard Dubois)
 - No orbital modulation since March 2009 flux increase!!!
- Is it "weather"? Are there longer-term cycles? More data needed!!

LS I Flux by Week



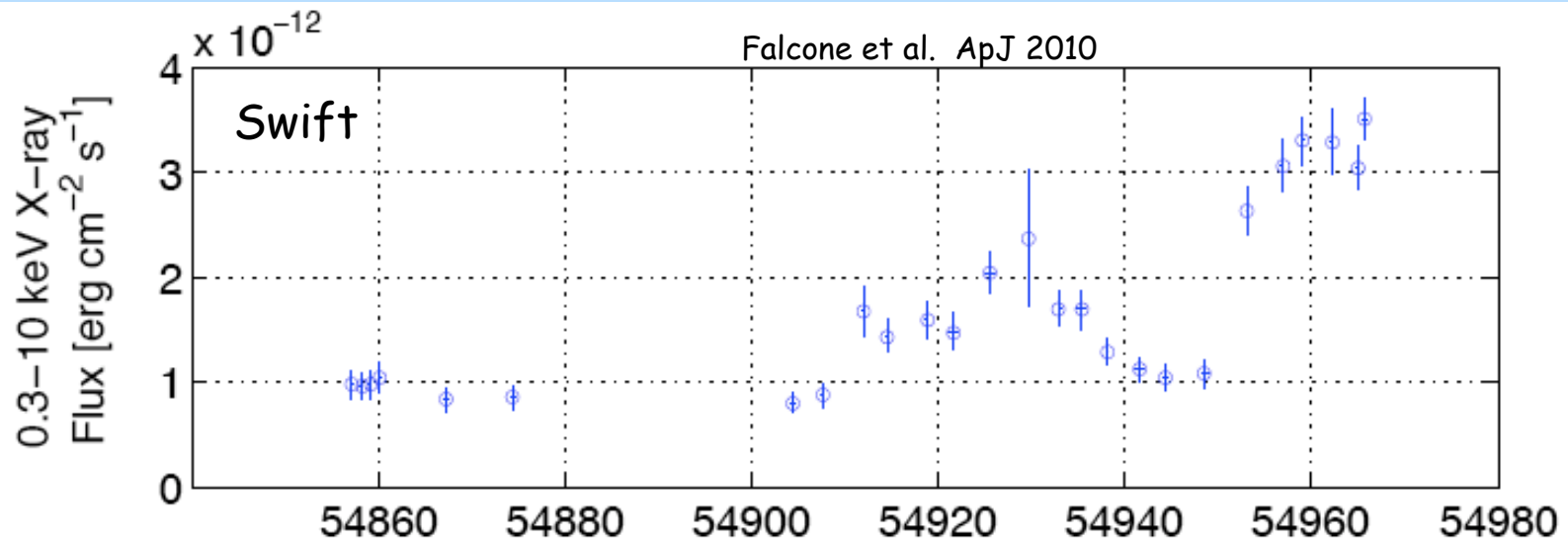
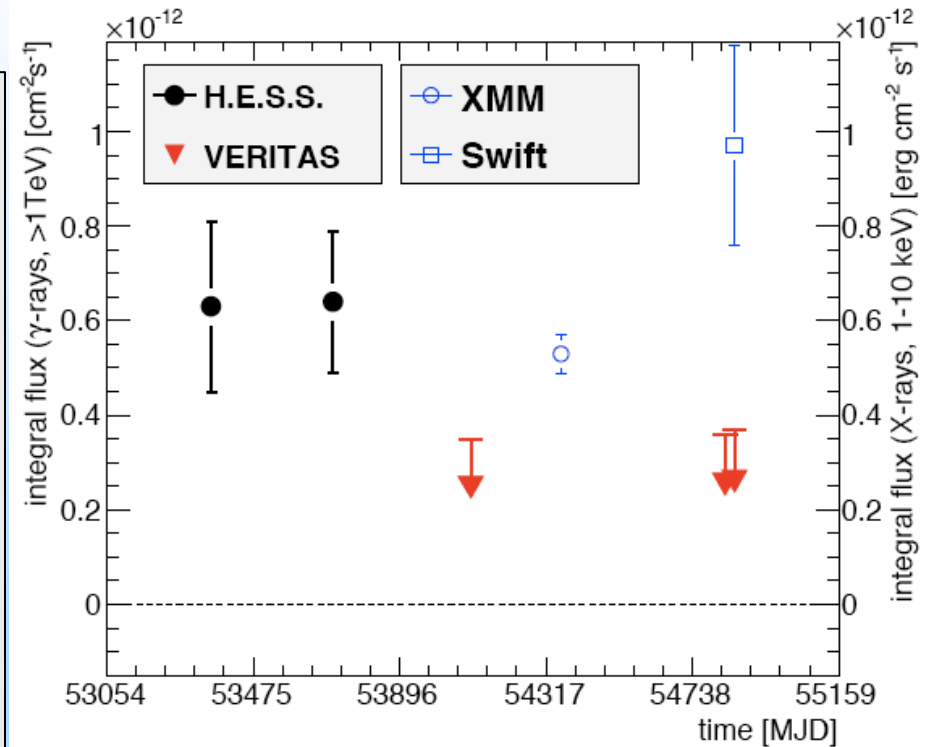
HESS J0632+057

- Unidentified TeV HESS source in the Galactic plane ($\Gamma=2.53$, Flux $\sim 3\%$ Crab)
- A rare unresolved source ($<2'$)
- VERITAS non-detection (2006 -2009) implied gamma-ray variability
- MWL follow-up shows a hard spectrum X-ray source ($\Gamma=1.2 - 1.9$) & faint radio source coincident with a B0pe star (MWC148). Not a Fermi source.
- Swift measures long term variability



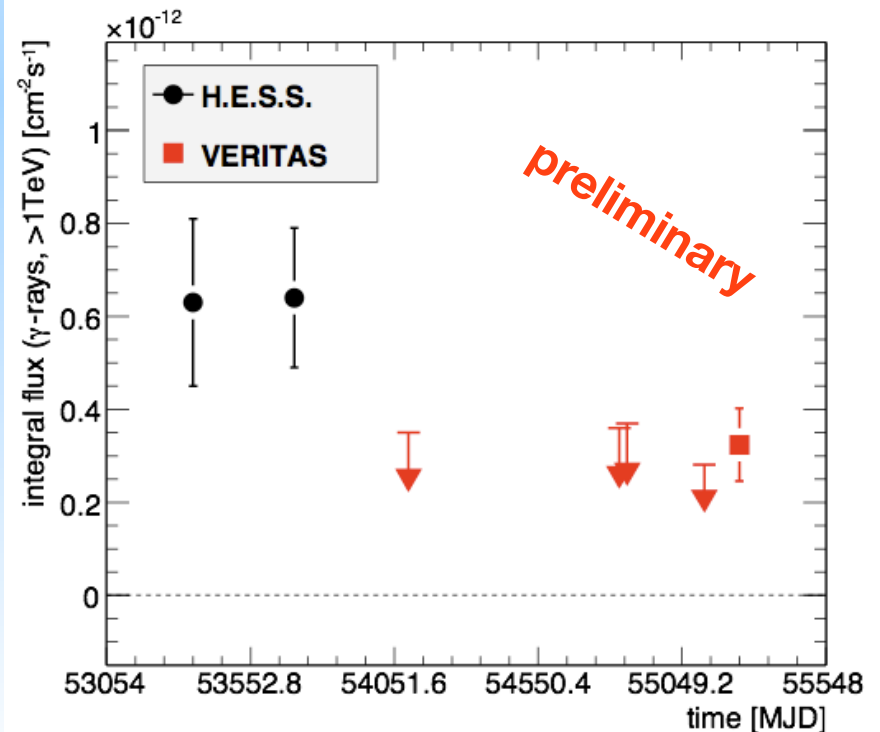
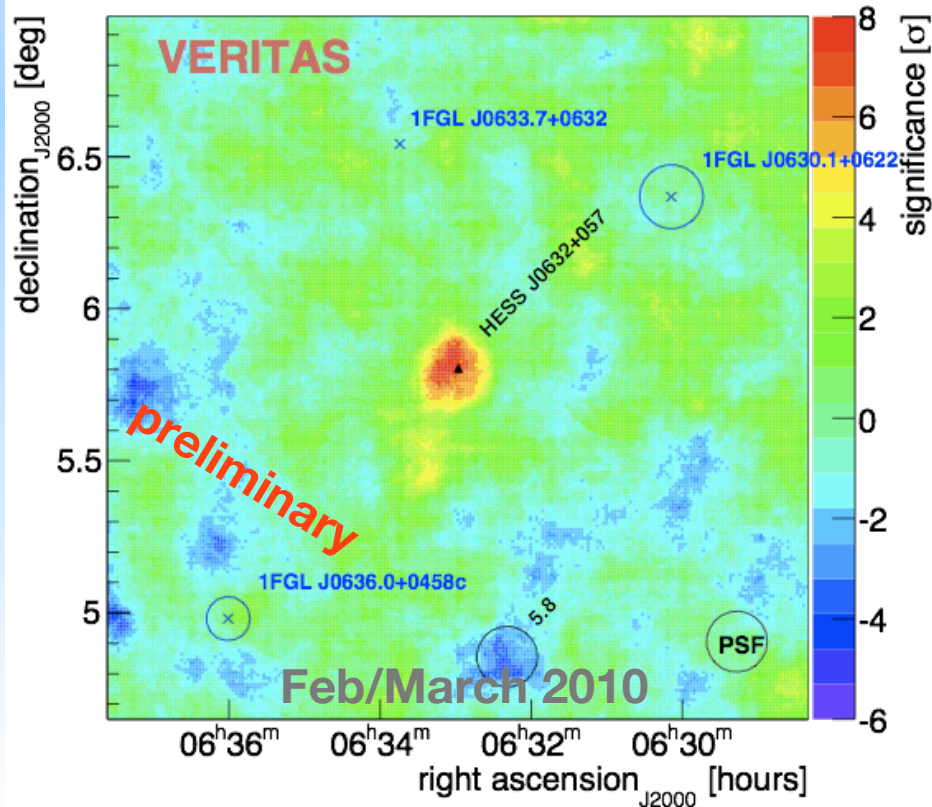
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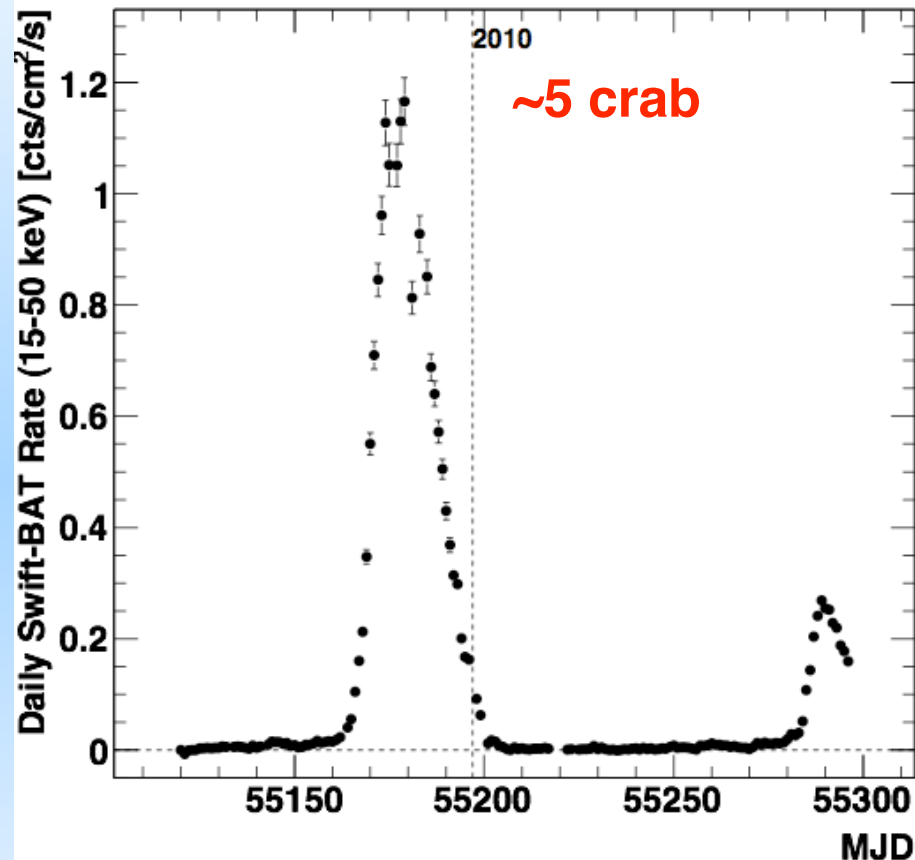
HESS J0632+057

- Recent observations show a clear VERITAS detection, at ~50% of the original H.E.S.S. flux (Gernot Maier, Jeff Grube)
- Position agrees with HESS J0632+057 and MWC 148
- More data needed! Is it a TeV binary? Detection of orbital modulation at any wavelength would be definitive.



1A0535+262

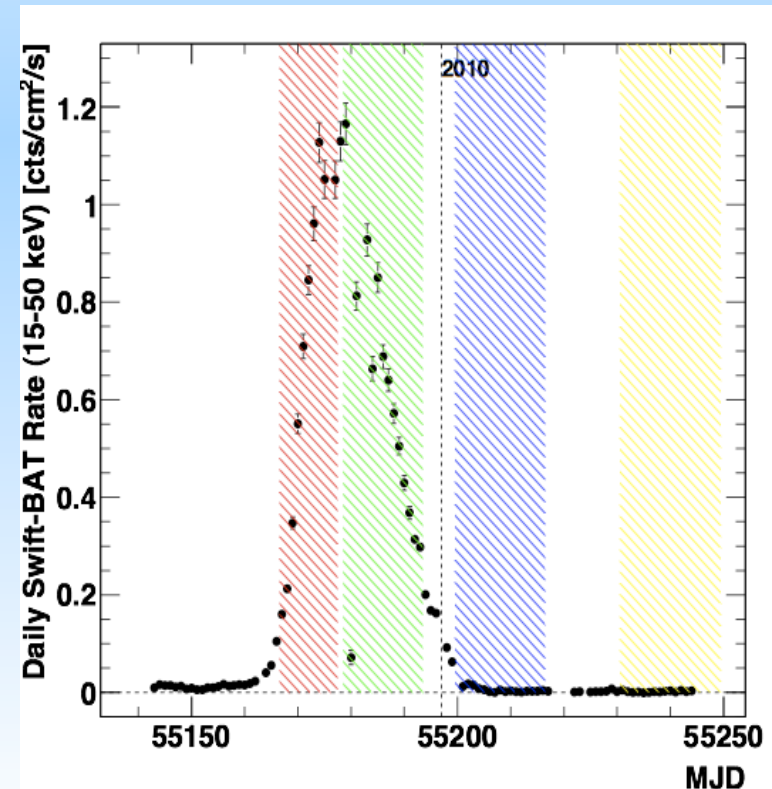
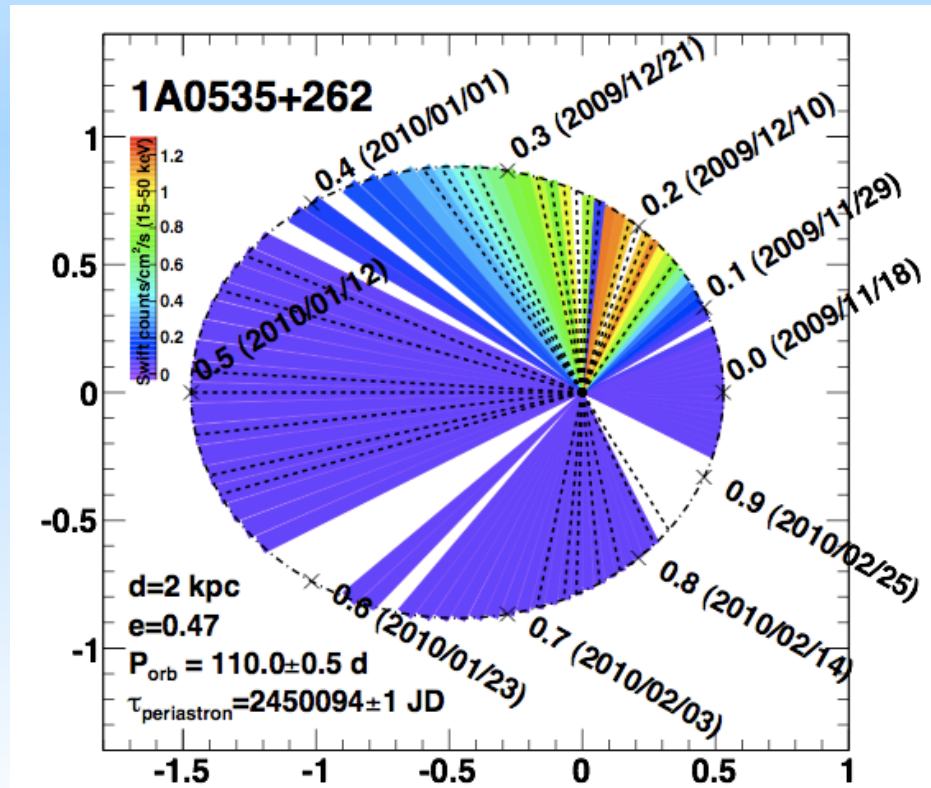
- HMXB, Be-star and X-ray pulsar (P_{Spin}=104s)
- Orbital period 110 d, eccentric orbit ($e=0.47$)
- Distance 2.4 ± 0.4 kpc
- Hard X-ray spectra; non-thermal particle populations
- Giant outbursts every ~ 5 years since 1975
- VHE emission?: Cheng & Ruderman mechanism; VHE maximum expected about 10-20 days after X-ray flare (Orellana & Romero 2004)



But: no detailed modeling for VHE emission, no flux prediction, SED, etc.

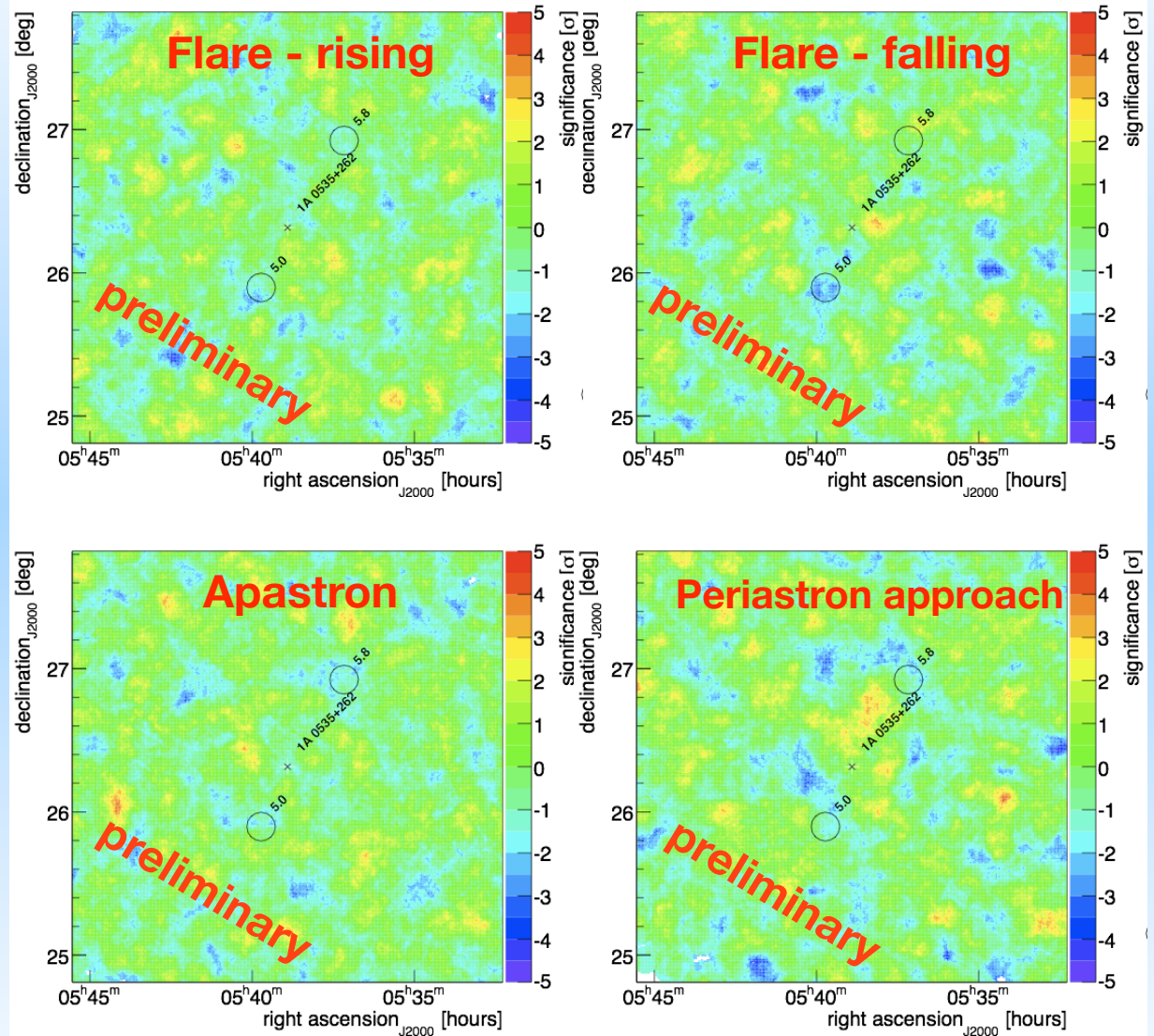
1A0535+262

- Dec 2009: ToO triggered on flaring Be/X-ray binaries
- 23 hours of data with VERITAS, all high elevations: mean $\sim 70^\circ$
- Good coverage of flare phase (rising/falling edge), apastron and periastron approach
- Flare occurred at best time for VERITAS



1A0535+262

- Results still in prep.
(Gernot Maier, Angelo Varlotta)
- 5-8 hours of VERITAS observations in each bin
- No VHE emission detected
- 99% flux upper limits above 300 GeV: 0.5-2% Crab Nebula flux
- Lots of data at other wavelengths available
- Definitive results with this generation of IACTs



Summary

- VERITAS is operating well
 - both surveying and pointed observations have been fruitful, but galactic time is limited. Pointing is the most efficient, especially post-Fermi.
- Gamma ray binaries continue to surprise
 - **LSI +61 303** is among the largest VERITAS datasets (~100 hours total)
 - Not detected in VHE since the Fermi launch, despite reasonable apastron coverage with a much more sensitive instrument
 - **HESS J0632+057** is a variable TeV and X-ray source
 - VERITAS now confirms the detection
 - Definitive measurement of **1A0535+262** during a flare state.

Open Questions

- Given the constraints on galactic observations with VERITAS, What should we look at?
- Binaries:
 - Is LSI+61303 definitely a pulsar/ Be star wind-driven system?
 - What are the true observational characteristics of the system?
 - How to explain these observations with fewest assumptions?
- What is HESS J0632+057?
- Where are the other binaries? Why no LMXRBs at TeV?

